Elk Population Estimates and Forecasts for Rocky Mountain National Park, 2009-2011

Executive Summary, October 2009

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We used modern statistical methods to bring together four decades of monitoring data with a mathematical model of population dynamics to estimate the current and future abundance of elk in Rocky Mountain National Park. Our purpose was to support decisions on elk management in the park in way that is explainable and defensible.

Model estimate of elk population size tracked the observed increase and decline of the abundance of elk in Rocky Mountain National Park during 1970-2009. We estimated that the downward trend in elk numbers seen during the last decade may have stabilized in 2009. Model estimates of the 2009 population size and forecasts for 2010 and 2011 were steady at about 600 animals, although there was considerable uncertainty in the forecasts.

There is a high degree of certainty that the current population is within or below the target range specified in the Elk and Vegetation Management Plan, 600 - 800 animals. Looking two years ahead and assuming moderate culling of 30-50 adult females, there is a 75-80% chance that the population will remain below the upper limit of 800 animals. However, there is also a significant chance (about 40-50%) that the population will fall below the lower threshold of 600 animals during 2010-2011.

The effects of increasing harvest outside the park during the past decade, culling within the park during 2008 and 2009, and treatment of a significant number of reproductive females with a persistent contraceptive have combined to reduce the elk population to levels that are within or below the target range specified in the elk management plan. It has been wisely said[1] that predictions are difficult, particularly when they involve the future, and our forecasts do not escape that difficulty. The model's near-term forecasts indicate there is some probability that the future population could exceed the upper limit of the target range, but that risk is substantially smaller than the risk that the population might continue to decline. Although the number of elk harvested from the area surrounding the park was lower in 2009 than during any year in the previous decade, the effects of reductions in the number of animals harvested were more than offset by effects of culling within the park and by the depressing effect of fertility control on recruitment. These effects create a risk that elk numbers might reach unacceptably low levels within the park if culling is continued in the absence of reductions in harvest around the park boundary.

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During 2008 and 2009, the elk population in Rocky Mountain National Park was managed using culling to achieve population objectives outlined in the Elk and Vegetation Management Plan. In addition, new census, classification, and harvest data were obtained to monitor the status of the population, and research was conducted on a fertility control agent. As part of the adaptive management process, data on the management actions were combined with the monitoring data in a population model to support decisions on the need for future population management. The model provides rigorous estimates of the probability that the population is, and will be, within the objectives specified in the Management Plan. These estimates can be used to evaluate the wisdom of alternative management actions, for example, the number of animals to be culled during the remainder of 2009.

This document describes how the model described in Hobbs and Hoeting (2008) was modified to include new data and to assess the effect of future management actions. We assume familiarity with the overall model and do not repeat its description here, focusing instead on changes that were made to accommodate new information and to improve the model's formulation. Revised estimates of the current population size and new forecasts of its future size are presented.

Management and Research Affecting the Elk Population

The culling that occurred in 2009 represented a departure from elk management in the park during the previous 30 years. Elk had not been removed by culling or relocation since 1968, and hunting has never been allowed inside the park boundaries. During spring of 2008, thirteen cow elk that tested positive for CWD were culled. In early January 2009, prior to the 2009 census, twenty elk were culled as part of the planned reductions in elk population size outlined in the Elk and vegetation Management Plan. These culls also supported ongoing research, described below. Immediately after census, thirteen more cows were culled as part of the planned reductions in elk population size outlined in the Elk and Vegetation Management Plan. To summarize, thirteen animals were culled after the 2008 census but before the 2008 births, twenty animals were culled after the 2008 births and before the 2009 census, and an additional thirteen were culled following the 2009 census and preceding the 2009 births.

In addition, a research project was initiated during 2008 to evaluate methods for live-animal testing for Chronic Wasting Disease (CWD) and to determine the efficacy of a fertility control agent to prevent pregnancy in free-ranging elk. The research was tightly integrated with plans for population management outlined in the Elk and Vegetation Management Plan. Adult elk females were treated with a persistent contraceptive after they became pregnant in 2008, which means that they could give birth in 2009, but, for the most part, will not do so in 2010. The effect of the contraceptive decays with time. Combined data from field and from paddock studies (Dan Baker, personal communication) showed that 19 out of 20 cows that were treated with contraceptives were infertile during the first year after treatment. Data from paddock studies indicate that 2 of 8 were pregnant in their second year and 4 of 8 were pregnant in their third year following treatment. These data were used to form prior distributions to estimate the proportion of cows that were treated that were infertile and associated uncertainty.

Modifications to the Process Model

Equations for juveniles and adult females were modified to represent effects of culling and fertility control as follows. The number of juveniles (age approximately 6 months) at census was calculated as

$$\mu_{1,t+1} = \log\left[s_2 r\left(N_{2,t} - \rho I_t\right) - rC_{pre,t} - a_2 H_{1,t} - a_3 a_2 H_{2,t}\right]$$
$$N_{1,t+1} \sim \text{lognormal}\left(\mu_{1,t+1}, \sigma_1\right) ,$$

where:

$\mu_{1,t+1}$ = the log of the deterministic mean number of juveniles at time t +1,
$N_{1,t+1}$ = the estimate of the number of juveniles a time t + 1 incorporating process uncertainty,
s_2 = probability of survival of adult females from census to births,
r = number of calves produced per female that survive to their first census,
ρ = probability that a female treated with a contraceptive is infertile,
I = number of females treated with contraceptives at time t,
$C_{pre,t}$ = number of animals culled after census at time t but before births,
a_1 = proportion of harvest of juveniles outside of the park that includes juveniles from inside the park,
a_2 = proportion of harvest of adult females outside of the park that includes adult females from inside the park,
a_3 = additive effect of adult female harvest on calf survival,
$H_{1,t}$ = juvenile harvest that occurs during time t to t + 1,
$H_{2,t}$ = adult female harvest at time t to t + 1,
σ_1 = the juvenile process uncertainty, on a log scale.

Estimation of the number of adult females was modified to include effects of culling:

$$\mu_{2,t+1} = \log\left(m\, s_1 N_{1,t} + s_2 N_{2,t} - C_t - a_2 H_{2,t}\right)$$
$$N_{2,t+1} \sim \text{lognormal}\left(\mu_{2,t+1}, \sigma_2\right) ,$$

where:
$\mu_{2,t+1}$ = the log of the deterministic mean number of adult females at time t +1,
$N_{1,t+1}$ = the estimate of the number of adult females a time t + 1 incorporating process uncertainty,
s_1 = probability of survival of juveniles from first census to second census,
s_2 = probability of survival of adult females from time t to time t+1[2] ,
C_t =number of adult females culled during time t to time t + 1,
$H_{2,t}$ = adult female harvest at time t to t + 1,
a_2 = proportion of harvest of adult females outside of the park that includes adult females from inside the park
σ_2 = the adult female process uncertainty, on a log scale.

Modifications to the Data Model

Scrutiny of the output presented in Hobbs and Hoeting (2009) revealed unrealistic ratios of bulls to cows. This occurred because composition data included in the data model were limited to observations of cows and calves. In our earlier work, we excluded bulls because of potential errors in counting them; however, we decided that approximate data on the male segment of the herd was superior to no data. To accommodate additional classification data on males, the data model for classification counts was changed from a binomial likelihood described in Hobbs and Hoeting (2009) to a multinomial formulation that admits data on juveniles, adult females and adult males (where adults are defined as animals 1.5 years and older), i.e,

$$\mathbf{O}_t \sim \text{multinomial}\left(\mathbf{p}_t, \text{trials}_t\right),$$

where $\mathbf{O}_t$ is a vector of observations of the number of juveniles, adult males, and adult females at time t; $\mathbf{p}_t$ is a vector of model's estimates of the proportion of each age / sex class in the population at time t, and $trials_t$ is the total number of animals observed (i.e., the sum of $\mathbf{O}_t$).

Results

Model estimates of the number of elk in Rocky Mountain National Park tracked the observed increase and decline in elk abundance during 1970-2009 (Figure 1). Model estimates also

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[2] All natural mortality is assumed to occur after census and before births.

reflected the preponderance of females in the population (Figure 1). The model estimated that the current population is about 600 animals (Table 1). Based on the data at hand and the model's assimilation of those data, it is virtually certain that the current population size is less than the upper limit on the target range (Table 1).

We used three scenarios to forecast abundance during 2010 and 2011. For all scenarios, we used Colorado Division of Wildlife projections (Sherri Huwer, personal communication) to estimate harvest for 2009 and assumed these would apply to 2010. We then evaluated three different culling regimes, assuming that 0, 30, or 50 more adult females would be culled before the 2010 census. We assumed no further culling would occur in 2010. The three scenarios gave similar forecasts. The model estimated that the downward trend in elk abundance seen in the data during the last decade may have stabilized in 2009. The median of the posterior distribution of model estimates of the 2009 population size and forecasts for 2010 and 2011 were steady at about 600

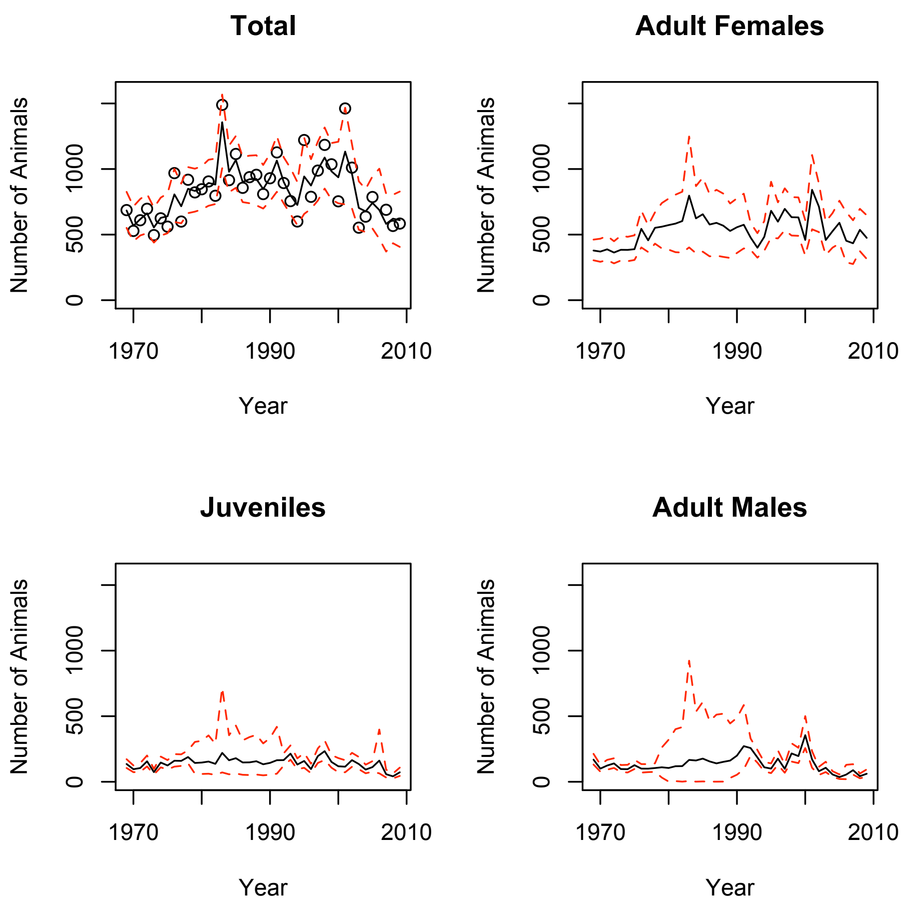

Figure 1. Median of the posterior distribution (solid line) of the estimated total number of elk and the number of adult females, juveniles, and adult males. Open circles give the mean estimate from census data. Dashed lines given 95% credible intervals. These intervals expand during the 1980's as a result of the absence of classification data during those years.

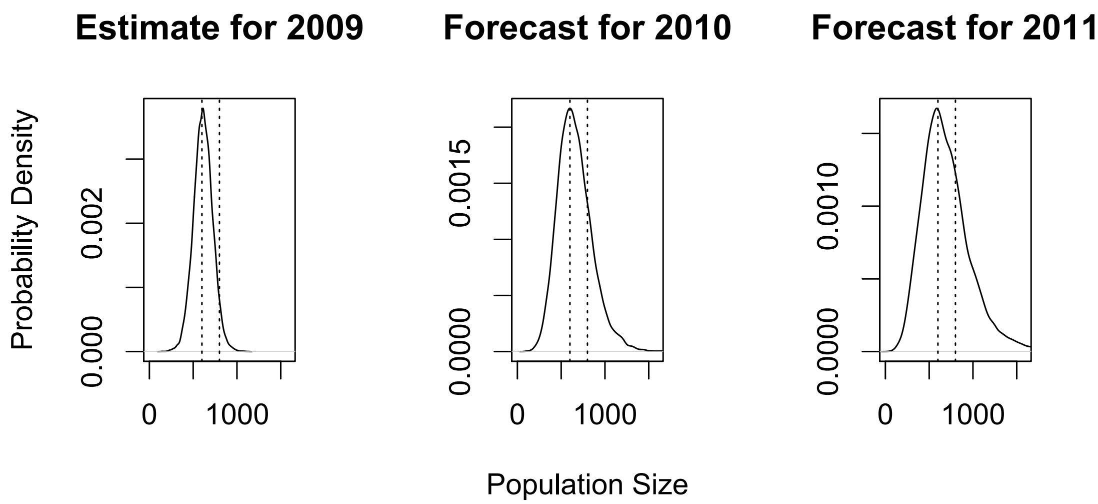

Figure 2. Posterior distributions for the estimated population size for 2009 and forecasts for 2010 and 2011. Forecasts include effects of fertility control and assume no additional animals were culled before the 2010 census and no culling after the 2010 census. Harvest projections for 2009 were used to estimate harvest during 2009 and 2010. Increasing width of the distribution implies greater uncertainty in the estimate or forecast.

Table 1. Estimates and forecasts of population size and probability that the RMNP elk population is within the target range during 2009, 2010, and 2011. Assumptions of forecasts are described in the legend for Figure 2.

Year	Median N (95% CI)	P(N ≤ 600)	P(600 < N ≤ 800)	P(N > 800)
2009	614 (409 - 839)	0.45	0.50	0.048
2010	637 (217-838)	0.42	0.37	0.21
2011	659 (175-1010)	0.40	0.29	0.30

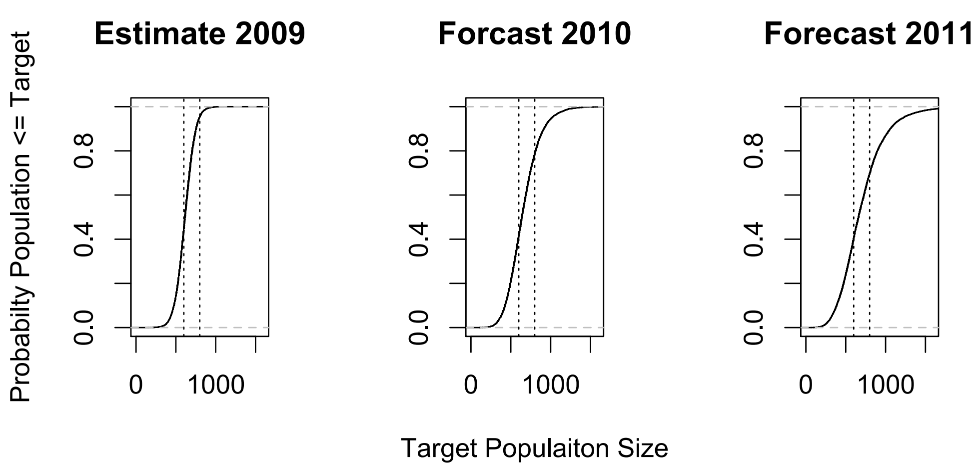

Figure 3. Probability that the model's estimate of the mean population size is less that the specified target population size. Vertical, dashed lines give upper and lower limit of target range. Assumptions for model forecasts are described in the legend for Figure 2.

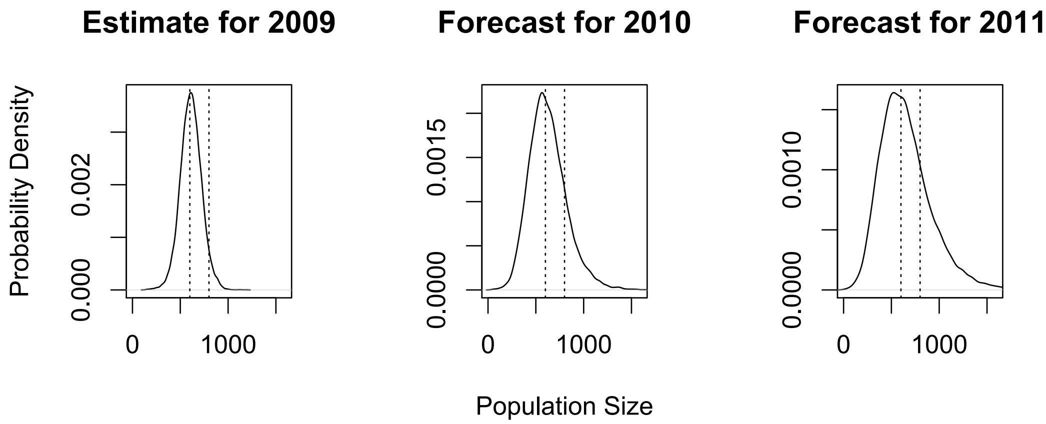

Figure 4. Posterior distributions for the estimated population size for 2009 and forecasts for 2010 and 2011. Forecasts include effects of fertility control and assume 30 additional animals were culled before the 2010 census and no culling after the 2010 census. Harvest projections for 2009 were used to estimate harvest during 2009 and 2010. Increasing width of the distribution implies greater uncertainty in the estimate or forecast.

Table 2. Estimates and forecasts of population size and probability that the RMNP elk population is within the target range during 2009, 2010, and 2011. Assumptions of forecasts are described in the legend for Figure 4.

Year	Median N (95% CI)	$P(N \leq 600)$	$P(600 < N \leq 800)$	$P(N > 800)$
2009	614 (409 - 839)	0.45	0.50	0.048
2010	608 (391-1073)	0.48	0.35	0.17
2011	622 (262-1349)	0.46	0.29	0.25

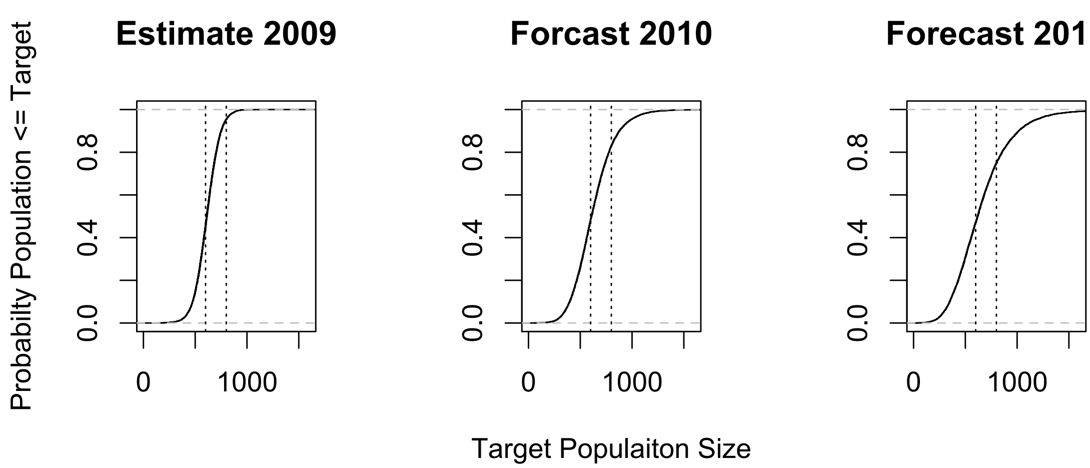

Figure 5. Probability that the model's estimate of the mean population size is less that the specified target population size. Vertical, dashed lines give upper and lower limit of target range. Assumptions for model forecasts are described in the legend for Figure 4.

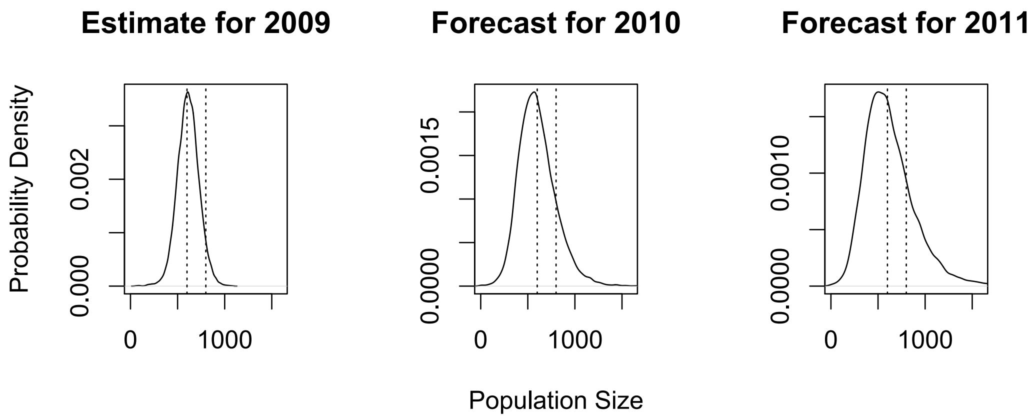

Figure 6. Posterior distributions for the estimated population size for 2009 and forecasts for 2010 and 2011. Vertical dashed lines show upper and lower bound of target range. Forecasts include effects of fertility control and assume 50 additional animals were culled before the 2010 census and no culling after the 2010 census. Harvest projections for 2009 were used to estimate harvest during 2009 and 2010. Increasing width of the distribution implies greater uncertainty in the estimate or forecast.

Table 3. Estimates and forecasts of population size and probability that the RMNP elk population is within the target range during 2009, 2010, and 2011. Assumptions of forecasts are described in the legend for Figure 6.

Year	Median N (95% CI)	P(N ≤ 600)	P(600 < N ≤ 800)	P(N > 800)
2009	614 (409 - 839)	0.45	0.50	0.048
2010	582 (286-1048)	0.54	0.31	0.14
2011	585 (230-1288)	0.52	0.25	0.21

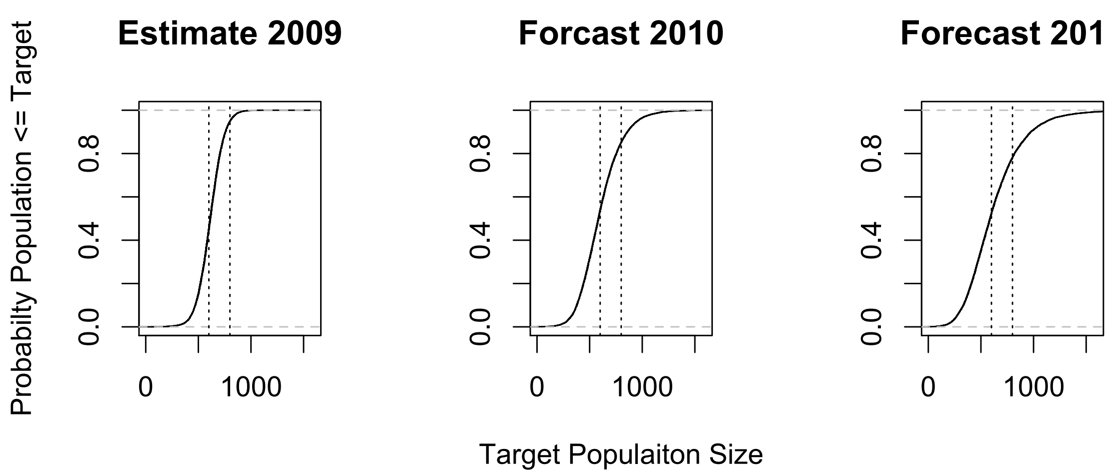

Figure 7. Probability that the model's estimate of the mean population size is less that the specified target population size. Vertical, dashed lines give upper and lower bound of target range. Assumptions for model forecasts are described in the legend for Figure 6.

animals (Figure 2-7, Table 1-3), although there was considerable uncertainty in the forecasts. There were no large differences in the probability that population would fall outside the target range among the three scenarios evaluated (Figure 2-7, Table 1-3). The 0 culling option had the lowest chance that the population would fall below the target range in 2010 (p = .41, Table 1), while the 50 animal option had the greatest chance of reducing the population below the lower limit of the range (p = .54, Table 3). Similarly, the 0 culling option had the greatest chance of exceeding the range in 2010 (p = .21), while the 50 animal option had the lowest chance (p = .14, table 3). Corresponding probabilities for the 30 animal cull option were intermediate to the 0 and 50 cull options.

Discussion

The effects of increasing harvest outside the park during the past decade, culling within the park during 2008 and 2009, and treatment of a significant number of reproductive females with persistent contraceptive have combined to reduce the elk population to levels that are within or below the target range specified in the elk management plan. Although the number of elk harvested from the area surrounding the park was lower in 2008 than during any year in the previous decade, the reductions in animals harvested were offset by culling within the park and by effects of contraception.

It has been wisely said[3] that predictions are difficult, particularly when they involve the future, and our forecasts do not escape that difficulty. The posterior distributions of model forecasts indicated there is some probability that the future population could exceed the target range in the near term, but that risk is substantially smaller than the risk that the population might continue to decline. The model we use here is exceedingly simple--it ignores a variety of processes that are known to influence elk population dynamics because the data on the operation of these processes is not sufficient to justify including them in the model. Notable among these processes is the potential effect of chronic wasting disease (CWD). Although the role of CWD in elk population dynamics remains uncertain, we can be sure that the disease is unlikely to accelerate population growth. These uncertainties are included in the model's estimates, and are one of the reasons that are forecasts become increasingly tenuous as we project further into the future. Nonetheless, the results presented here present a picture of an elk population that appears to be static in the near term, but that may be declining. These possibilities have a greater weight of evidence than the possibility of increase.

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Literature Cited

Hobbs, N. T. and J. A. Hoeting. 2008. A Stochastic Model of Population Dynamics for the Rocky Mountain National Park Elk Herd. Unpublished technical Report, Rocky Mountain National Park.